Effect of Virtual Reality Training Using Leap Motion Controller on Impairments and Disability in Patients with Wrist and Hand Stiffness

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Abstract

Background and Purpose: Virtual reality (VR) training targets not only the musculoskeletal, but also the neurological system and has been successfully used in neurological rehabilitation. Our objective was to test whether there are any benefits of adding VR training with conventional physiotherapy on impairments and disability of wrist and hand stiffness, in patients with distal forearm fractures and early rheumatoid hand affection.

Methodology: In this experimental study, 50 patients suffering from wrist and hand stiffness were alternately allocated into either Conventional physiotherapy group and VR with conventional physiotherapy group. Both the groups completed 8-12 training sessions over a period of 4 weeks comprising of similar protocol of conventional physiotherapy with only the VR group receiving additional VR training. Patient was assessed on outcome measures pre and post treatment.

Results: All the outcome measures showed significant improvement in both groups. On between group comparisons, the VR group showed significantly greater improvements on the outcome measures of grip strength, dexterity (left hand and assembly), wrist flexion, ulnar deviation, forearm range of motion and work component of Michigan Hand Questionnaire when compared to the conventional group. There were no differences between groups on outcome measure of pain, wrist extension, wrist ulnar deviation and total disability score of Michigan Hand Questionnaire.

Conclusion: We conclude that, adding virtual reality training to conventional physiotherapy has benefits on outcome of grip strength, hand dexterity, work component of disability and direction specific improvement in the range of motion of wrist and forearm as compared to conventional physiotherapy alone.

Key Words: *Virtual Reality Training, hand rehabilitation, Gaming, distal end forearm fractures.*

Introduction

Human hand is a highly evolved distal functioning part of the upper extremity. Function of the human hand is not only limited to prehension and manipulation of objects, but it also serves as a medium of interaction with the environment and tool for communicative gestures. This is possible due to the musculoskeletal system integrity coupled with a highly developed neurological system that controls hand function[1]. Any injury to the forearm hand complex can adversely affect the hand function.

Impairments of pain, deficits in fine dexterity and reduction in grip strength persist in patients in the long

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term after distal end radius fracture[2,3,4]. Functional impairments of hand stiffness and weakness were associated with difficulty in return to their work, even after one year in patients post distal radius fracture.[5] Moore CM & Leonardi-Bee J, have demonstrated that moderate to very severe disability persists in patients up to one year post distal radius fracture.[2] Hence, it is important to provide appropriate rehabilitation to the patients presenting with hand conditions in order to lower the incidence of complications over a period of time. [6,7]

A wide variety of exercises, addressing both impairments and functional deficits are utilised in hand rehabilitation. More recently, technology in the form of Virtual Reality (VR) based therapy has become an important medium of rehabilitation by physical therapists. Virtual Reality therapy refers to a broad class of interventions, but can generally be defined as technological interventions that alter properties of the physical world[8]. VR technologies have emerged within medical research in recent years for treating acute pain, and proved to be an effective strategy based on pain distraction[9,10]. In neurological conditions, like Parkinson's disease treatment with VR training have demonstrated improvements in the motor learning[11]. In musculoskeletal conditions, use of VR showed reduction in pain intensity and neck disability and improved cervical ROM in the short term.[12]

A number of VR gadgets are now available like Microsoft Kinect, Nintendo Wii-Fit etc., but they do not primarily detect fine hand and finger movements, and hence, would be of limited benefit in hand rehabilitation. The Leap Motion Controller (LMC) is a low-cost, marker-less motion-capture device that tracks the fine movements of fingers and hands using neither data gloves nor markers[13]. LMC device can track the movement of multiple hands and fingers, within sub-millimetre accuracy. The usability of the device in the early rehabilitative phase in stroke patients was good to excellent[14]. Virtual reality training with LMC device has been shown to facilitate motor recovery and dexterity of a paretic upper limb[13]. However this device is less explored with in hand conditions of musculoskeletal origin. Hence, the objective of our study was to assess whether adding Virtual Reality therapy has additional benefit over only conventional Physiotherapy on impairments and disability in patients with wrist and hand stiffness.

Methodology

Study Setting and participants

The study was conducted at the D.Y. Patil Hospital & Research Centre, Navi Mumbai.

Ethical permission was obtained from the Institutional Review Board. Patients between the age of 18-70 years, with residual wrist and hand stiffness, post wrist fractures/ injury or due to rheumatoid arthritis were included in the study after obtaining an informed consent. The aetiology included distal end radius (DER), distal end ulna (DEU), mid-shaft radioulnar fractures with ORIF plating and Rheumatoid Arthritis presenting with wrist and hand pain but free of deformities.

Patients were excluded if they were suffering from any condition affecting the shoulder or elbow joint, having cognitive impairments or neurological conditions like Parkinson's disease Stroke, etc.. Pregnant women and patients with rheumatoid arthritis with hand deformities, and tendon injuries, nerve injures of the upper limb were also excluded from our study.

Study Design

The study design was an intervention based parallel group study. The participants were alternately allocated using single blinding method into two groups: Experimental/Virtual Reality Training group (Group I) and Conventional group (Group II).

Group I included supervised virtual reality (VR) training combined with conventional physiotherapy and the Group II included only supervised conventional physiotherapy.

Outcome measures

Patients were then assessed by physical examination on the aforementioned outcome measures before and after intervention. Pain was measured with Visual Analogue Scale (VAS); wrist and hand range of motion (ROM) using the Universal Goniometer; Grip Strength using Jamar Dynamometer; Hand Dexterity using Perdue Pegboard and hand disability using the Michigan Hand Questionnaire (MHQ).

The Michigan Hand Questionnaire is a valid and a reliable tool used in the assessment of hand conditions incorporating components of pain, aesthetics, function, work and satisfaction.[15,16] The grip strength measured using the Jamar Dynamometer has high inter-rater reliability, high accuracy and strong validity.[17] Abundant research has been done in healthy population for hand dexterity using the Purdue Pegboard, a tool with well-established validity and reliability.[18]

Intervention

For *Group I*, treatment protocol consisted of 15-20 minutes of conventional physiotherapy, followed by VR training for 10-15 minute. Patient in this group, received 2 sessions/ week of training with VR.

The patient was seated on a chair with back rest and elbows supported. VR was delivered with Leap Motion Controller device (Leap Motion Inc, 2013) that consists of an optical sensor which works with computer interaction. Leap Motion Controller (LMC) is a motion based device specially designed for acquisition of 3D positions and orientations of hands and fingers. The device consists of two monochromatic IR cameras and three infrared LEDs giving the device a semi-spherical observational area with a distance of approximately 1 meter.[19] There are more than 30 online free downloadable games that can be used for rehabilitation at the LMC gallery. We chose five games appropriate to our protocol. Each game used for the treatment purpose had a variety of levels and progression to the next level occurred only on completion of the previous level. If the patient was unable to progress due to discomfort or incompetency for the previous level, he/she would not be progressed to the next level.

Group II received conventional physiotherapy under the supervision of the therapist for 25 minutes/session. The treatment protocol for the conventional physiotherapy included muscle stretching, joint mobilisation, range of motion and strengthening exercises for wrist and hand muscles, as per the impairments.

Patients of each group received a total of 8-12 sessions of treatment over a period of 4 weeks i.e. 3 sessions/week. The total number of sessions were same for both the groups. The patients in both the groups were assessed on outcome measurements pre-intervention and after 4 weeks of intervention.

Statistical analysis

The statistical analysis of the study was done using the "R Programming" software and 95% confidence level was used so that level of significance was set at $p = 0.05$, two-tailed. The distribution of the outcome measures was checked using the test for Normality - Kolmogorov-Smirnov test. The results showed that the data was not normally distributed and hence non-parametric tests have been used for further analysis of the outcome measures. Wilcoxon test was used to conduct within group analysis and Mann-Whitney U for between group analysis.

Results

Fifty participants with injury to forearm hand complex were alternately allocated to either conventional physiotherapy or VR group. The age of the patients matched at baseline between the two groups (p value = 0.992, which is >0.05).

Table 1 demonstrates patient characteristics in each group. Patients demonstrated moderate to severe pain, moderate to severe hand disability and dominant hand more affected than the non-dominant. There were no significant differences between the groups at baseline (P> 0.05) on demographics measures.

Table 1

Parameter	VR group	Conventional Group
Mean Age (years)	48.8	47.9
Gender – Male: Female ratio	10:15	10:15
Dominance - right: left	19:6	19:6

Cont... **Table 1**

Affected hand – right: left ratio	13:12	14:11
VAS	7.04	6.96
MHQ- Overall	40%	46%

Values are presented with numbers or percentage.

Tables 2 and 3 demonstrate within group change in outcome measures pre-intervention and post-intervention for VR group & conventional respectively with statistical analysis. Within group statistical analysis indicate that both the groups improved on all outcome measures (Table 2 & 3).

Table 2: Within group changes in parameters in VR Group, presenting results of pre and post intervention

Outcome Parameters		**Pre- intervention**	**Post- intervention**	**p value#**
Pain (VAS)		7.04±0.89	1.76±1.13	.000*
Grip Strength (kg)		6.72±3.45	8.88±3.59	.000*
Swelling(cm)		41.68±3.56	38.96±2.86	.000*
Dexterity (Purdue Peg board)	Left	9.48±3.06	11.64±2.12	.000*
	Right	10.88±2.03	12.36±1.68	.000*
	Both	7.24±1.67	8.6±1.63	.000*
	Assembly	4.56±1.36	5.96±1.46	.000*
Disability (MHQ)	Overall	40.60±20.78	73.00±21.51	.000*
	ADL 1 hand	44.80±29.84	87.00±11.18	.000*
	ADL 2 hand	70.76±17.80	93.10±6.86	.000*
	ADL Overall	59.67±22.52	91.16±7.28	.000*
	Work	15.60±9.86	68.40±10.07	.000*
	Pain	52.60±29.62	8.80±7.54	.000*
	Aesthetics	38.49±23.30	86.22±12.90	.000*
	Satisfaction	46.37±27.36	85.97±6.90	.000*

***Cont...* Table 2: Within group changes in parameters in VR Group, presenting results of pre and post intervention**

Wrist & Forearm ROM	Flexion	42.2±14.80	77.84±8.27	.000*
	Extension	33.20±20.51	63.12±11.79	.000*
	Ulnar Deviation	17.72±4.55	27.4±4.79	.000*
	Radial Deviation	16.28±5.91	26.48±5.04	.000*
	Supination	46±23.58	84.6±5.39	.000*
	Pronation	62.28±30.16	89.60±1.38	.000*

*significant #Wilcoxon Signed Ranks Test

Table 3: Within group analysis of changes in parameters in Conventional Group pre intervention and post intervention:

Outcome Parameters		Pre-intervention	Post- intervention	p value#
Pain (VAS)		6.96±0.84	2.16±1.49	.000*
Grip Strength (kg)		7.48±3.96	8.76±4.38	.000*
Swelling(cm)		40.88±2.99	38.64±2.74	.000*
Dexterity (Purdue pegboard):	Left	11.04±2.03	12.52±1.78	.000*
	Right	11.56±2.14	13.24±1.42	.000*
	Both	8.32±2.29	9.64±2.23	.000*
	Assembly	4.20±1.19	5.12±1.09	.000*
Disability (MHQ)	Overall	46.00±18.71	83.00±14.22	.000*
	ADL 1 hand	48.00±24.28	87.40±8.18	.000*
	ADL 2 hand	68.81±23.19	93.12±8.18	.000*
	ADL Overall	62.19±19.74	91.60±5.77	.000*
	Work	26.00±17.38	70.60±10.24	.000*
	Pain	47.40±23.59	7.20±7.08	.000*
	Aesthetics	49.48±26.82	86.00±10.70	.000*
	Satisfaction	49.41±19.14	87.15±9.00	.000*

Cont... **Table 3: Within group analysis of changes in parameters in Conventional Group pre intervention and post intervention:**

Wrist & Forearm ROM	Flexion	49.32±14.26	73.44±11.45	.000*
	Extension	39.08±17.23	63.12±16.00	.000*
	Ulnar Deviation	21.4±8.07	26.44±5.74	.000*
	Radial Deviation	14.56±4.63	23.16±6.32	.000*
	Supination	55.6±21.95	77.24±13.77	.000*
	Pronation	76.88±20.77	89.4±1.66	.002*

*significant #Wilcoxon Signed Ranks Test

On between group comparisons, the VR group showed significantly greater improvement in grip strength, dexterity, wrist flexion, ulnar deviation, forearm supination, forearm pronation, and the work component of the MHQ, when compared to the conventional group. Whereas, there was non-significant difference between the two groups on the other outcome measures i.e. pain; wrist swelling; dexterity of right and both hands; wrist extension; wrist radial deviation; components of MHQ (overall, ADL, pain, aesthetics and satisfaction) (Table 4)

Table 4: Between group changes in parameters post intervention

Outcome Parameters		**VR Group Mean Difference (Pre-post treatment)**	**Conventional Group Mean Difference (Pre-post treatment)**	**P value**
Pain (VAS)		5.28±1.40	4.80±1.71	0.217
Grip Strength(kg)		2.16±0.62	1.28±0.84	0.000*
Swelling (cm)		2.72±1.65	2.24±1.27	0.504
Dexterity (Purdue Pegboard)	Left	2.16±1.18	1.48±0.77	0.042*
	Right	1.48±0.77	1.68±1.28	0.663
	Both	1.36±1.22	1.32±0.80	0.830
	Assembly	1.40±0.82	0.92±0.70	0.014*
Disability (MHQ)	Overall	32.40 ±26.93	37.00±14.86	0.969
	ADL 1 hand	42.20±24.28	39.40±23.86	0.666
	ADL 2 hand	22.34±13.14	24.32±17.16	0.930
	ADL Overall	31.49±17.86	29.42±16.76	0.381
	Work	52.80±19.32	44.60±14.50	0.038*
	Pain	43.80±28.00	40.20±20.69	0.527
	Aesthetics	47.73±21.15	36.52±20.93	0.057
	Satisfaction	39.60±23.61	37.74±15.00	0.711

Cont ... **Table 4: Between group changes in parameters post intervention**

Wrist & Forearm ROM	Flexion	35.64 ±14.67	24.12±10.91	0.012*
	Extension	29.92±16.51	24.04±13.85	0.178
	Ulnar Deviation	9.72±4.39	5.04±4.94	0.002*
	Radial Deviation	10.2±5.28	8.6±6.24	0.234
	Supination	38.6±20.23	21.64±15.26	0.003*
	Pronation	27.32±27.10	12.52±20.83	0.045*

* significant change #Mann-Whitney U test

Discussion

The purpose of this study was to test whether Virtual Reality Training has any additional benefits over Conventional Physiotherapy on impairments and disabilities in musculoskeletal related wrist and hand stiffness.

In this study, female patients were more than the male patients (Table 1). This can be attributed to the fact that females being more prone to osteoporosis as a result of menopause and are more prone to fractures as compared to males.[20] Most of the patients included in the study suffered from distal end radius fracture. This can be explained by the overall high incidence and prevalence of upper extremity fractures in adults and distal end radius fracture constituted to 18% of all the fractures in the adult population.[21,22]

Effect on Pain:

Patients in this study were suffering from moderate to severe pain post trauma or rheumatoid arthritis. The significant reduction of pain in both groups could be attributed to the exercises incorporated in protocol for both Groups (Table 2 & 3). Our results are in concordance with previous research reporting pain reduction with administration of exercises in patients with DER fractures[23,24].

It has been hypothesized pain reduction with VR occurs via distraction due to increased activity of the anterior cingulate cortex and orbitofrontal region of the brain, due to the high cognitive demand placed while playing the games. This is accompanied by a decreased activity of the pain matrix through attention, emotion and other senses (e.g. visual, auditory) to modulate pain during distraction[25].

Effect on Swelling:

In within group analysis, a significant reduction in swelling was observed in both the groups. This is because the treatment protocol in this study involved exercises with the hand in an elevated position. Also, patients were taught hand exercises in elevation as a part of their home program in order to reduce the swelling.

Effect on Grip Strength:

While patients in both the groups had a significant increase in grip strength, there was significantly more increase in the grip strength in the VR group, as compared to Conventional group (Table 4). Although there was no real-world resistance during the VR training, it can be attributed to the neural facilitation that takes place in the early rehabilitative phase[26,27] with the use of repetitive pinch and grip movements.[13]

Effect on Dexterity:

In within group analysis, a significant improvement in dexterity was observed in each group. Between group comparison, shows that there was a significant improvement in dexterity (left hand and assembly) in the VR group on comparison with the conventional group. This could be attributed to the intense, highly repetitive and task-specific movements required with VR training.[28] Repeated practise of the affected limb may lead to neural re-organisation[29] of the imitation-dependent cortex neuroplasticity through mirror neural networks[30]. Additional improvements in dexterity can be attributed to the neural requirements such as having a

good attention[31], hand-eye coordination, maintaining the position of the hand in space and performing fine motor movements while playing the VR based games.

Previous studies have demonstrated improvement in both dexterity and motor deficits after VR based training but in a different pathology i.e. stroke patients with neurological deficit in upper limb.[32,33] We have observed similar benefits as reflected by significant improvement in dexterity in our patients with musculoskeletal hand affection.

Effect on Hand Function:

Post treatment there was a significant improvement in the hand function as measured using MHQ in both the groups. On between group comparisons, a significant improvement in the work component was observed in the VR group, which can be an incidental effect due to the higher percentage of working individuals in the VR group, as there was no significant difference on the total MHQ scores. In our study, 84% of the study subjects in the VR group were working as opposed to 75% subjects in the conventional group.

Effect on Wrist and Forearm Range of Motion:

Both the groups had a significant improvement in the wrist and forearm ROM is observed in the conventional and the VR group (Table 2 & 3). This improvement is in line with previous research which shows that joint mobilization helps in improving wrist range of motion[34].

On between group comparisons, significantly more improvement was observed in the VR group in the ROM of wrist flexion, ulnar deviation, forearm supination, forearm pronation with no difference on wrist extension and radial deviation. This could be due to the position adopted by the patient as per the requirement of the game. The games used in our protocol required the wrist to be in the flexed position and forearm in mid-prone or pronation for 10 minutes intermittently, with some other requiring to perform repetitive wrist radial and ulnar deviation.

Conclusion

Virtual Reality training and Conventional training are both individually effective in improving wrist range of motion, grip strength, hand dexterity and reducing and pain disability in patients with wrist and hand stiffness post distal forearm fractures and early rheumatoid arthritis hand affection.

However, adding virtual reality training to conventional physiotherapy led to greater improvement in grip strength, hand dexterity, wrist flexion, ulnar deviation and forearm range of motion. There was an additional benefit on work component of disability with VR training, but not on overall disability in these patients. Whether direction specific movement improvement occurs with VR training can be explored in detail in future research.

Forthcoming studies can investigate the effect of virtual reality training as a home program treatment in patients with musculoskeletal involvement of wrist and hand.

Limitations:

The duration of treatment in the VR group was 10-15mins more than the conventional group, which could be reason of better outcome in VR group. Single blinding method was used in our study. Patients with two diverse pathologies i.e. distal forearm fractures and early RA affection were included in this study.

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